




EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Overview of Electric Energy Storage Systems

Essential Assets to the Electric Enterprise

Net-Zero-Energy Installations & Deployment Bases Workshop

February 3, 2009

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Electric Power Research Institute

Presentation Outline

- Introduction to the Electric Power Research Institute
- The Scale of Electricity Demand and the need for a Full Portfolio – Solutions for a Low Carbon Future
- Overview Electric Energy Storage Options
- Why is Electric Energy Storage is an Essential Asset in the Smart Grid
- Discussion and Q&A

Electric Power Research Institute (www.epri.com)
One of America's Largest and Most Successful R&D Consortia

- Serving over 1,000 energy-related organizations, including 150 international participants, in over 42 countries
- U.S. members represent over 90% of all electricity generated
- $300 million annual budget
  - ~ $ 30 M in Technology Innovation
- Global network of alliances
- Leadership in:
  - Development of Smart Grid
  - Clean Energy R&D
  - Plug-in Hybrid Vehicles
  - Nuclear Energy
  - Clean Coal

Key Messages

- The U.S. is in an Energy Crises > Transportation > Electric Power > Higher Electric Costs and Cost of Peak Power;
- The Electric Sector Emits over 30% of the US GHG Emissions; A Full Portfolio of Supply and Demand Energy Solutions will be needed;
- The Future Generation Mix will include a portfolio Variable Renewable Generation Sources;
- **The Electric Sector can not Inventory "Electrons" !**
- Energy Efficiency and advanced load management and control will be an essential part of the solution – enabled by a 'Smart Grid'
- Numerous electric energy storage systems are available **today** for application in Zero-Net-Energy Applications

- More Energy Storage Demonstrations are needed!

Electric Energy Storage is an Essential Asset in the Smart Grid

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The Scale of Electricity Demand

- 2007 U.S. electricity consumption ~ 3800 TWh
  - NY metro area ~ 89 TWh/year (as of 2006)

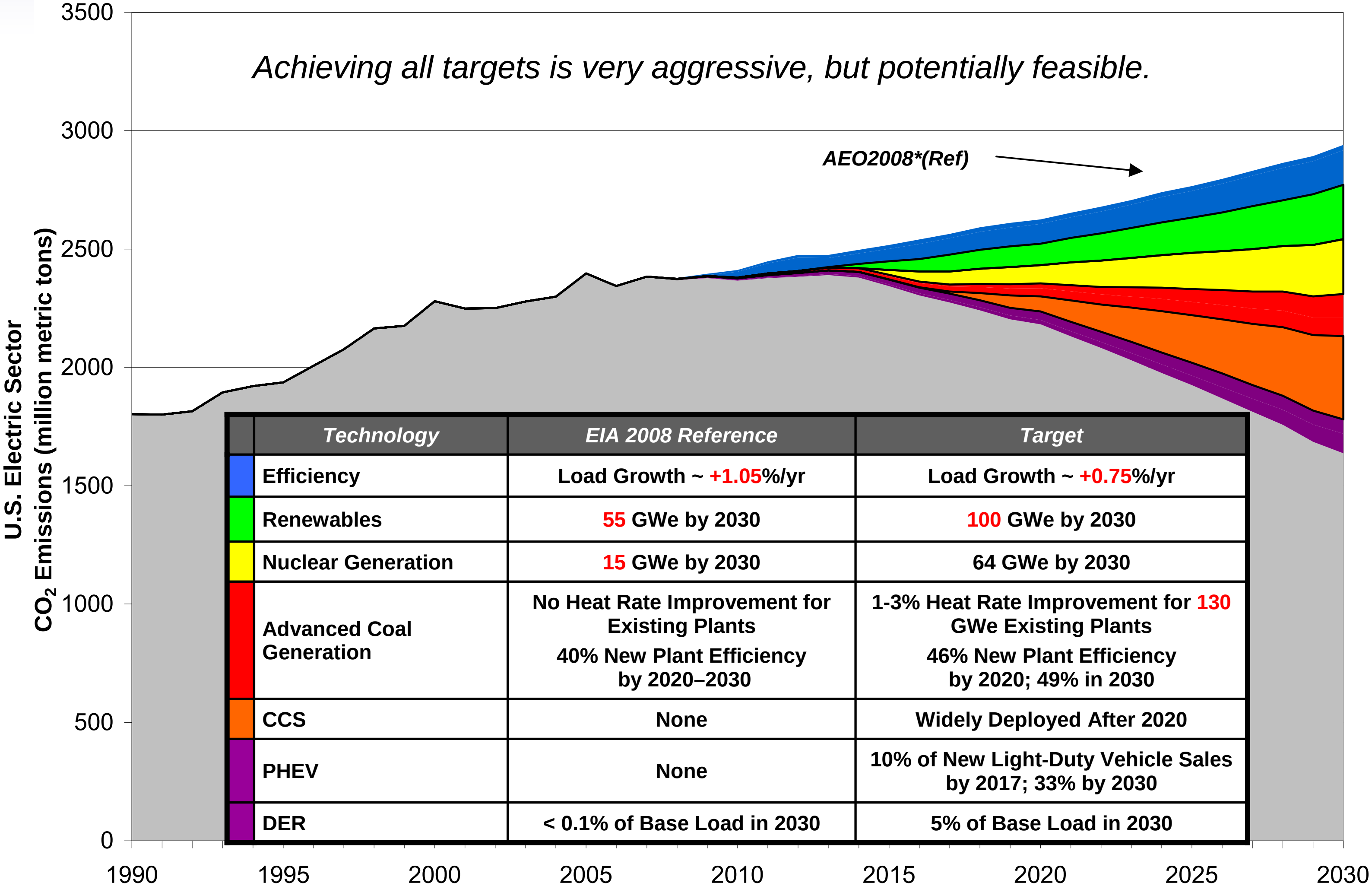
- Energy Information Agency 2008 Annual Energy Outlook
  - Projects **1150** TWh (**30%**) increase in U.S. electricity consumption by 2030.
  - ~Equivalent to addition of 13 New York metro areas

The Scale of Electricity Demand
1150 TWh needed by 2030

- Scale of generation
  - One advanced light water nuclear plant (1400 MW, 90% CF) ~ 11 TWh
  - One coal plant (500 MW, 80% CF) ~ 3.5 TWh
  - One natural gas turbine (400 MW, 40% CF) ~ 1.4 TWh
  - One 100 MW Wind Farm (100 1 MW Turbines, 40% CF) ~ 0.35 TWh

Full Portfolio of Energy Solutions needed for a Low Carbon Future

Technical Potential for CO_2 Reductions

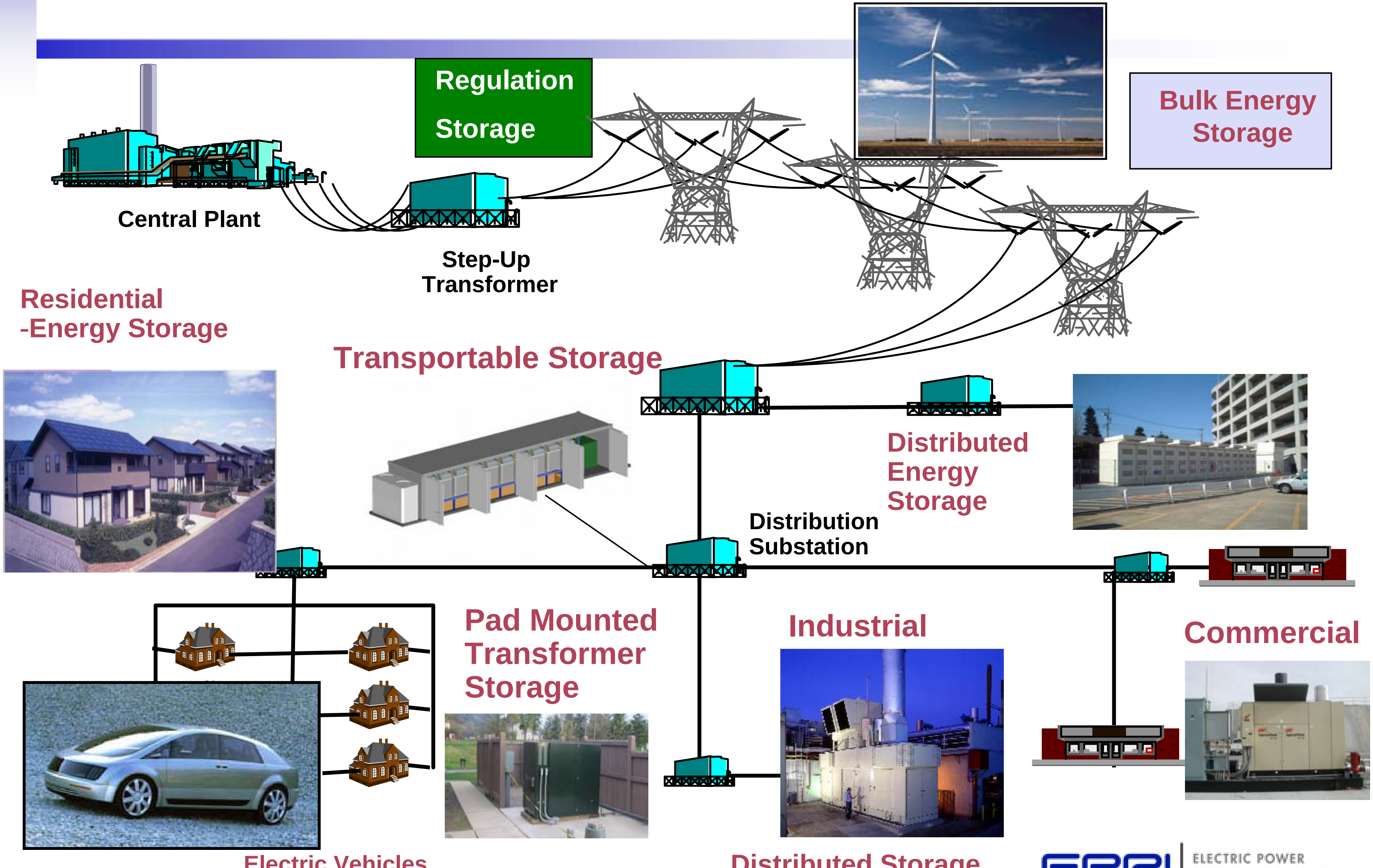


Technology	EIA 2008 Reference	Target
Efficiency	Load Growth ~ +1.05%/yr	Load Growth ~ +0.75%/yr
Renewables	55 GWe by 2030	100 GWe by 2030
Nuclear Generation	15 GWe by 2030	64 GWe by 2030
Advanced Coal Generation	No Heat Rate Improvement for Existing Plants 40% New Plant Efficiency by 2020–2030	1-3% Heat Rate Improvement for 130 GWe Existing Plants 46% New Plant Efficiency by 2020; 49% in 2030
CCS	None	Widely Deployed After 2020
PHEV	None	10% of New Light-Duty Vehicle Sales by 2017; 33% by 2030
DER	< 0.1% of Base Load in 2030	5% of Base Load in 2030

*Energy Information Administration (EIA) Annual Energy Outlook (AEO)

Electric Energy Storage

Locational Opportunities for Energy Storage in the Electric Enterprise



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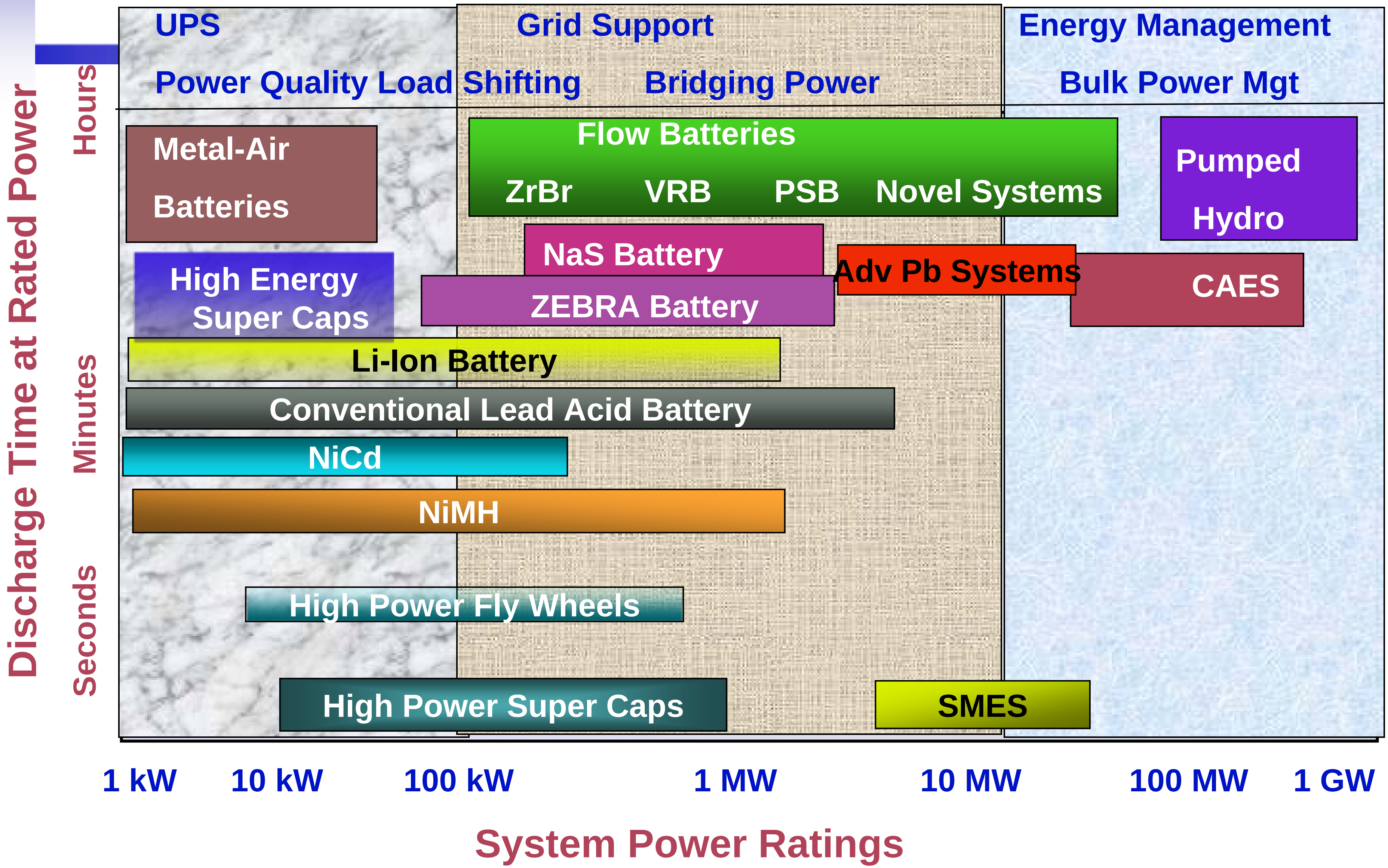
Positioning of Energy Storage Options



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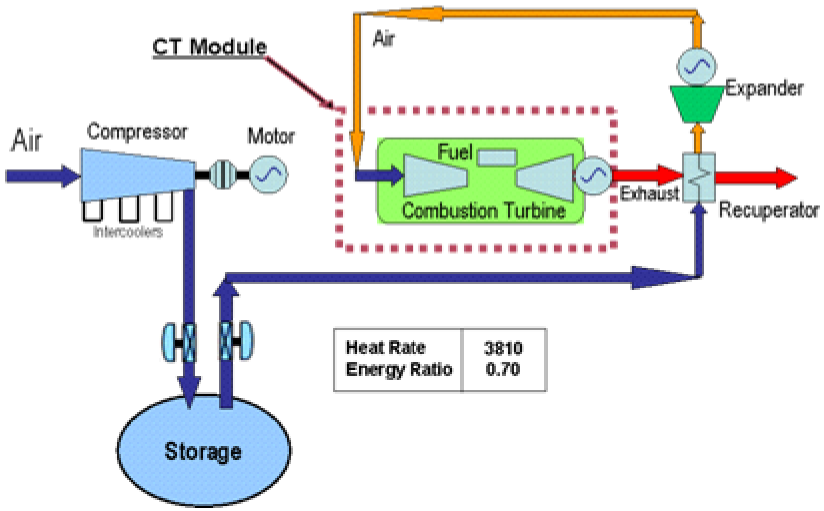
A Snapshot of current Energy Storage System Costs

Energy Storage Technology Capital Cost Estimates (Aug, 2008 Dollars)

Storage Type (See all footnotes)	$/kW	$/kWh	H (See Footnote 4)	Total Capital Cost $/kW (See Footnote 1)
Compressed Air Energy Storage				
Large (100-300 MW), Below Ground Air Store -Salt Geology	590-730	1-2	10	600-750
Small (10-20MW), Above Ground Air Store	700-800	200-250	4	1500-1800
Pumped Hydro				
Conventional (1000 MW)	1500-2000	100-200	10	2500-4000
Battery (10 MW), See Footnote 3				
Lead Acid, commercial	420-660	330-480	4	1740-2580
Sodium Sulfur, projected	450-550	350-400	4	1850-2150
Flow Battery, projected	425-1300	280-450	4	1545-3100
Flywheel (10 MW) commercial	3360-3920	1340-1570	0.25	3695-4313
Superconducting Magnetic Storage commercial	200-250	650,000-860,000	1 sec	380-489
Super-Capacitors Projected	**250 - 350**	**20,000 - 30,000**	**10 sec**	**300 - 450**

1. EPRI 8/2008
2.All figures are rough order -of -magnitude estimaes and are subject to changes as better information becomes available
3.Total capital costs include power conditioning system and all equipment necessary to supply power to the grid.
Not included are battery replacement costs, site permitting, interest during construction and substation costs.
4. These costs are for the storage hours shown +/- 25%
5. Cost vary depending on the price of commodity materials and region of country.

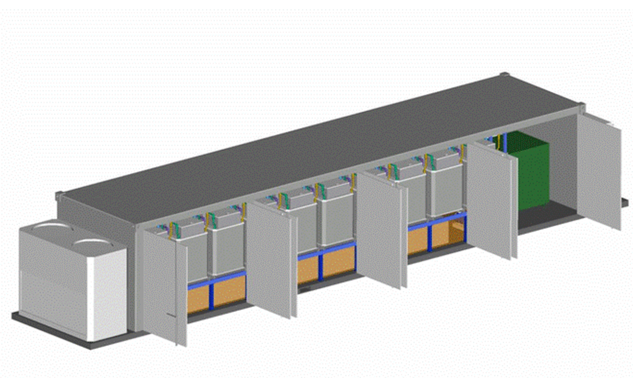
What is New and Exciting in Electric Storage?



400 MW / 10 hr CAES

1 MW / 7 hr NaS

1 MW / 15 min Li-ion

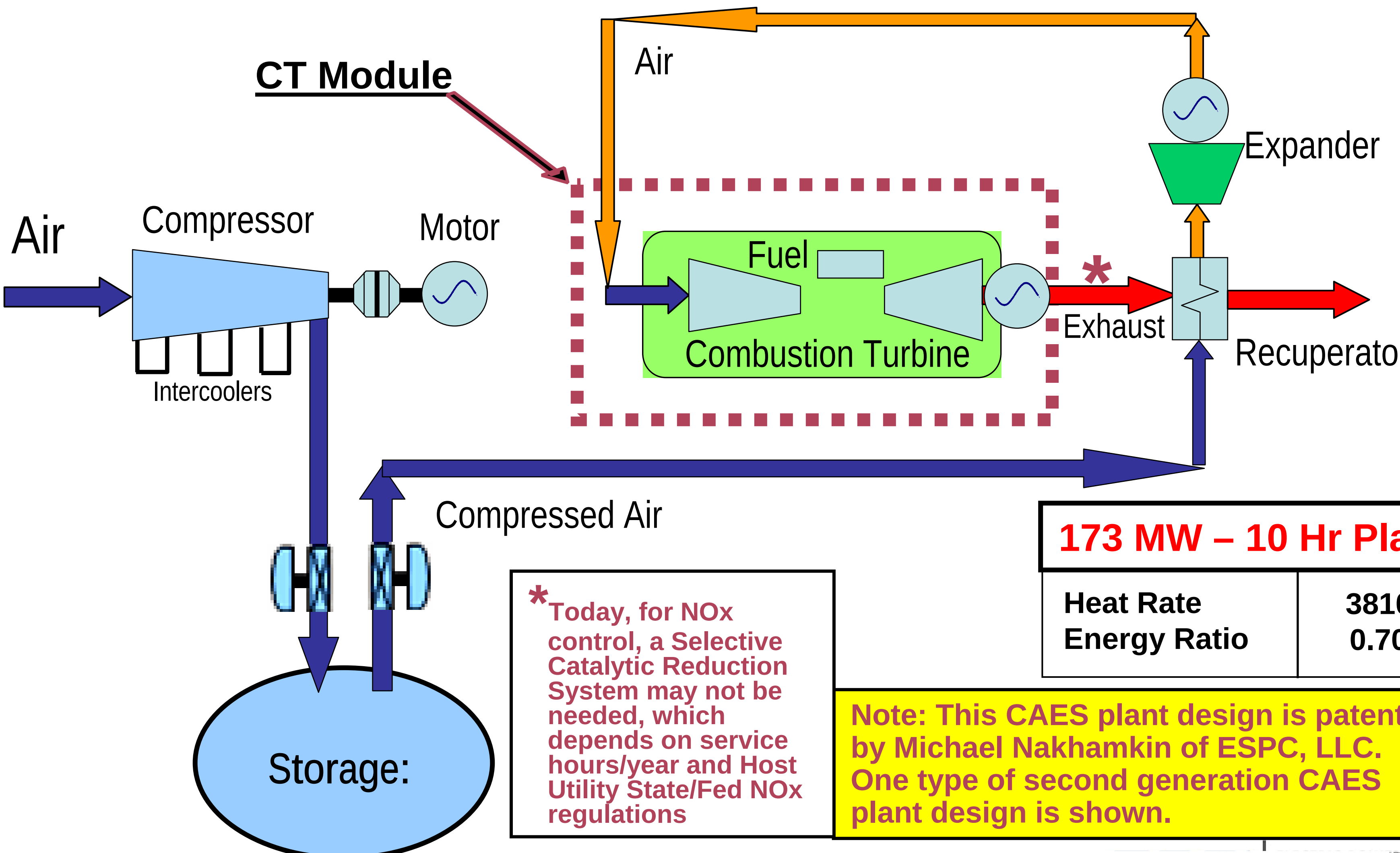


0.5 MW / 4 hr ZnBr

20 kWh Li-ion System

2nd Generation Compressed Air Energy Storage Plant

EPRI's Current Recommended Best Option for Bulk Energy Storage

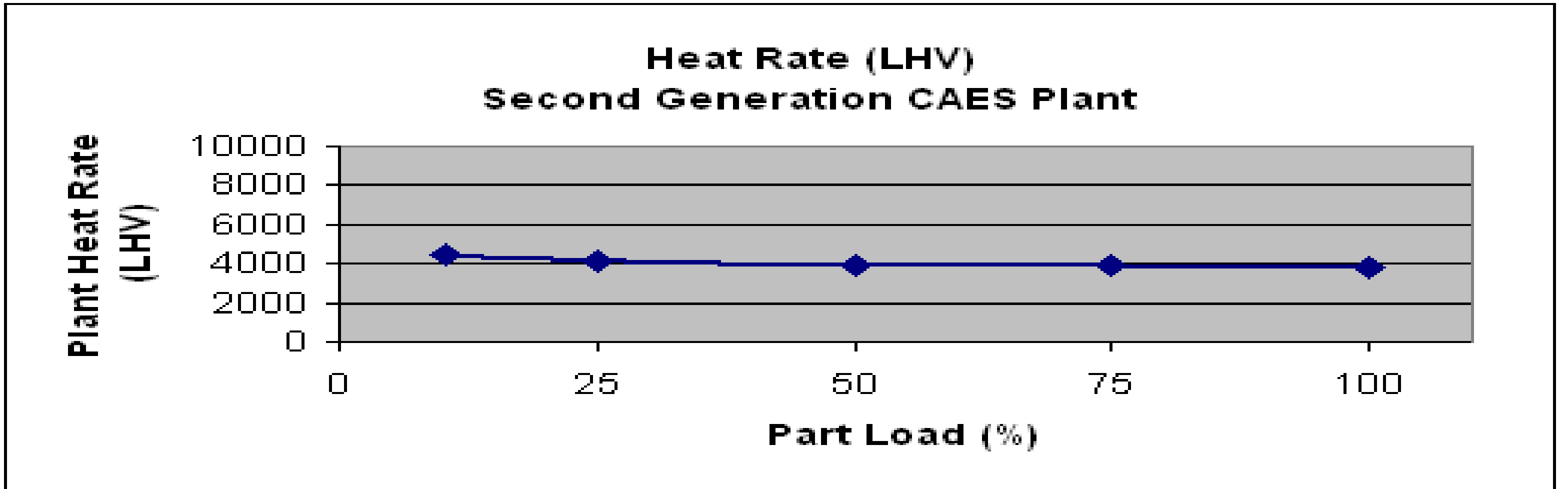


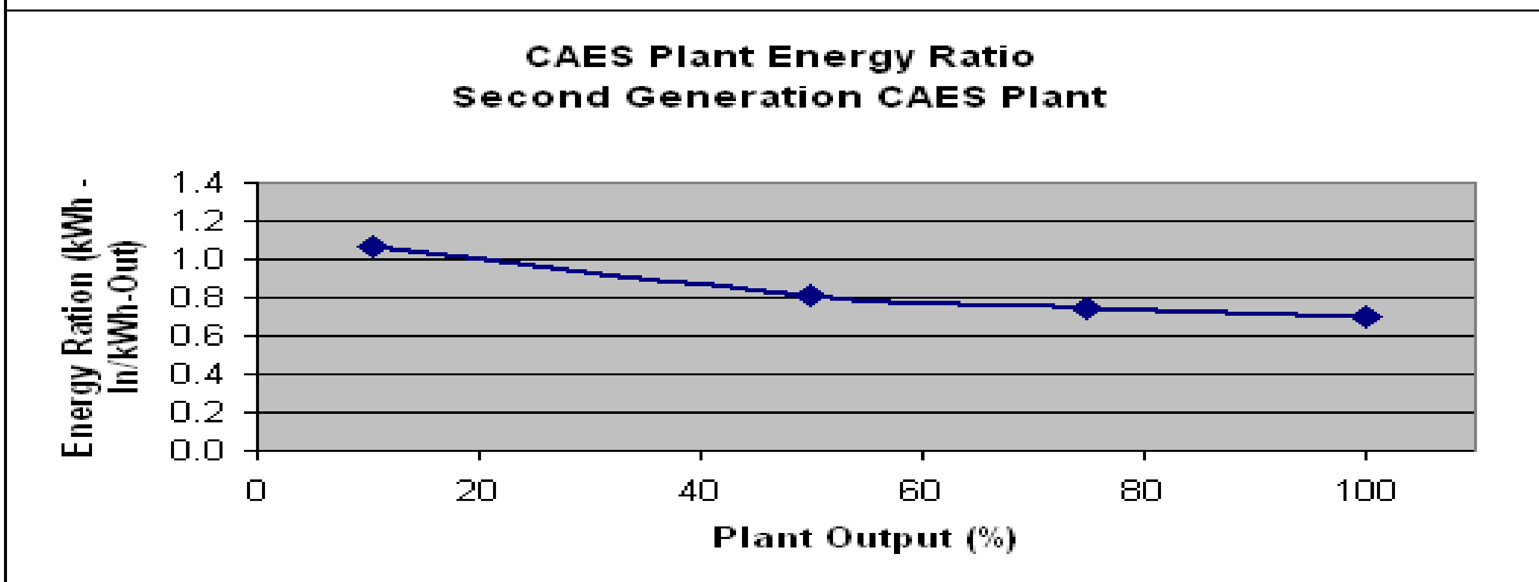
*Today, for NOx control, a Selective Catalytic Reduction System may not be needed, which depends on service hours/year and Host Utility State/Fed NOx regulations

173 MW – 10 Hr Plant	
Heat Rate	3810
Energy Ratio	0.70

Note: This CAES plant design is patented by Michael Nakhamkin of ESPC, LLC. One type of second generation CAES plant design is shown.

Second Generation CAES Plant: Estimated Part Load Operational Performance Metrics

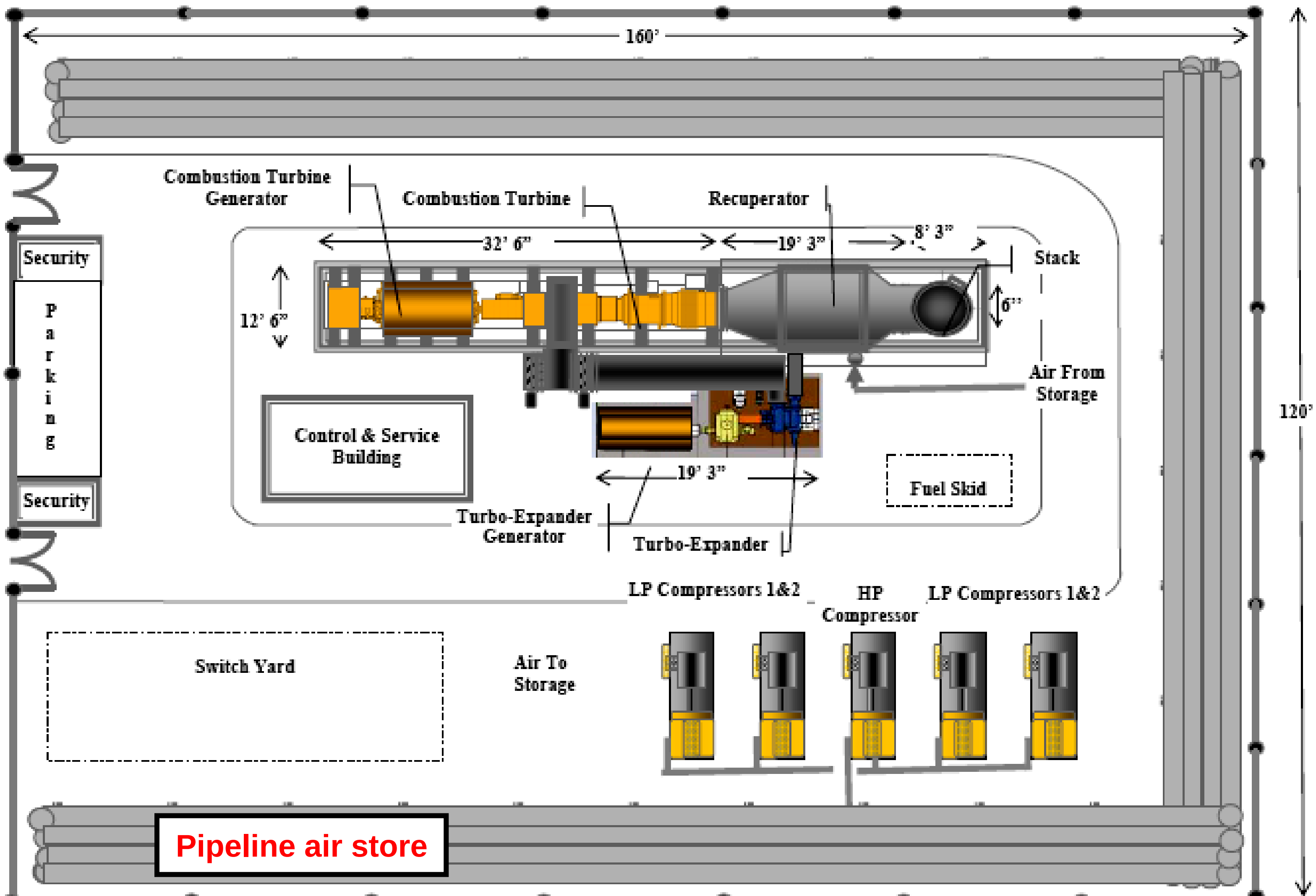




2nd Generation CAES Plant (15MW – 2 Hr) With Above Ground Air Store

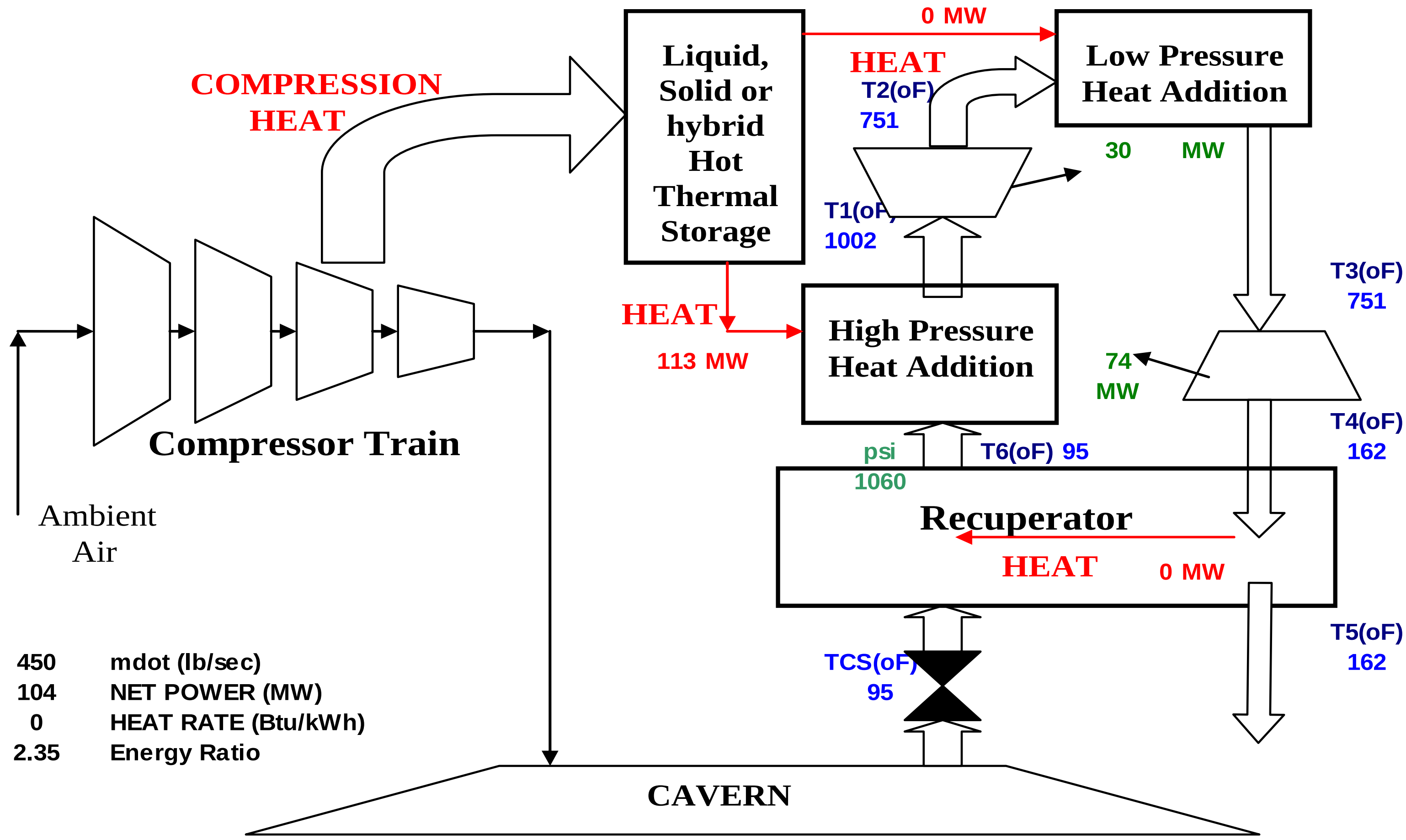
Capital Cost: $1500/kW to $1800/kW

Added capital cost for one more hour of storage: $200/kW to 250 $/kW



Advanced CAES Cycles

Adiabatic Systems will not require fuel



Potential CAES Location Sites

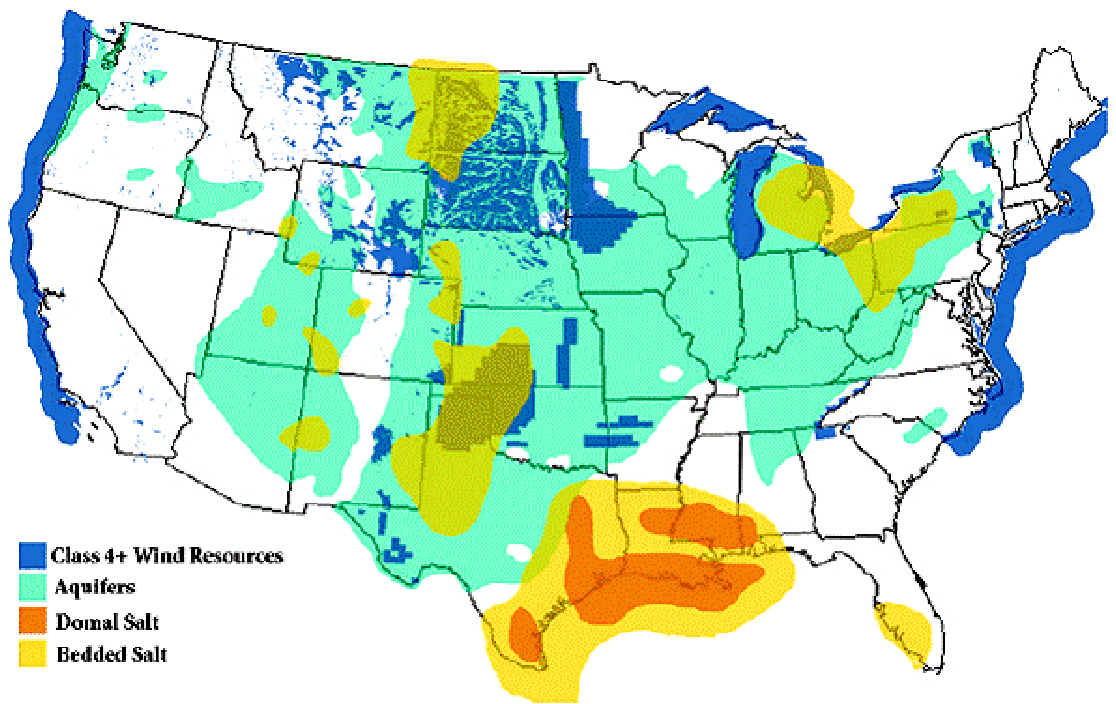


Figure i Areas with geologies favorable for CAES and class 4+ winds

Source: Succar, S. and R. Williams. "Compressed Air Energy Storage: Theory, Operation, and Applications." March 2008.

Why Electric Energy Storage is an Essential Asset in the Smart Grid?

- Managing Increased Wind Penetration
- Ancillary Services
- Managing Grid Peaks and Outage Mitigation
- Increasing the value of Distributed Photovoltaic systems
- Energy Storage as part of the Virtual Power Plant

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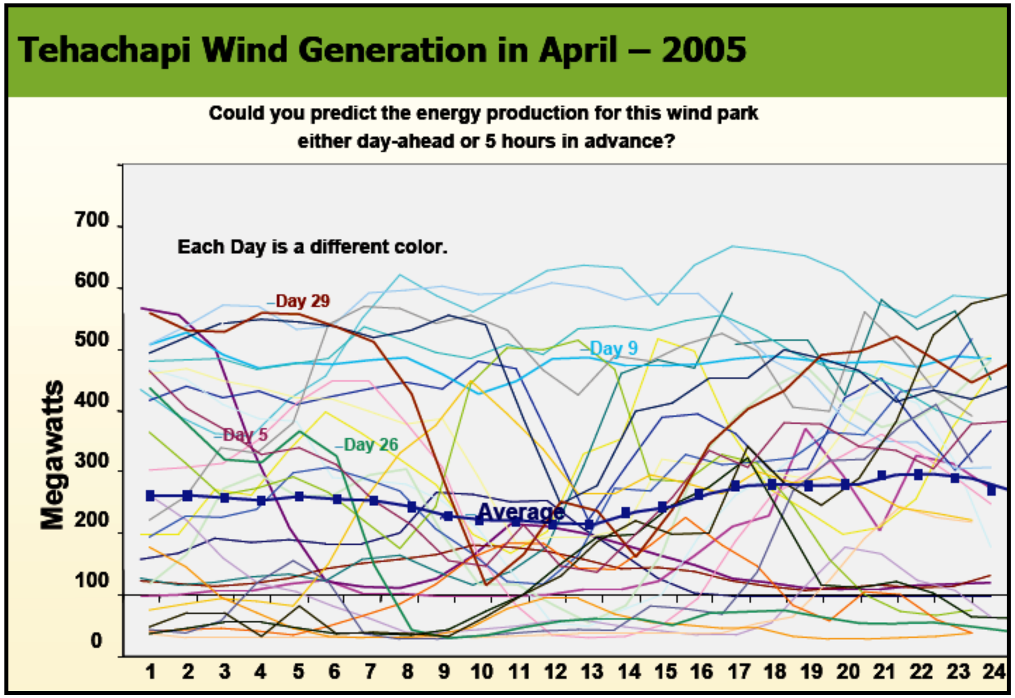
Wind Power
Large Power Fluctuations



Utility-Scale PV Generation

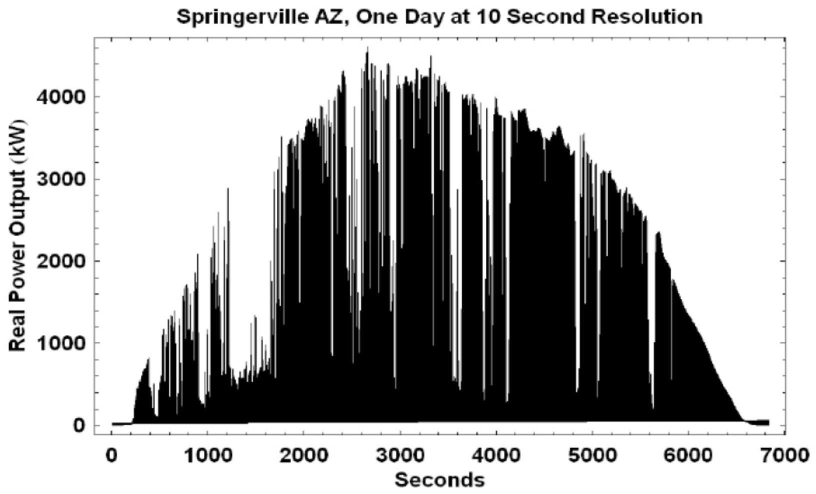
210-kV grid support at substation

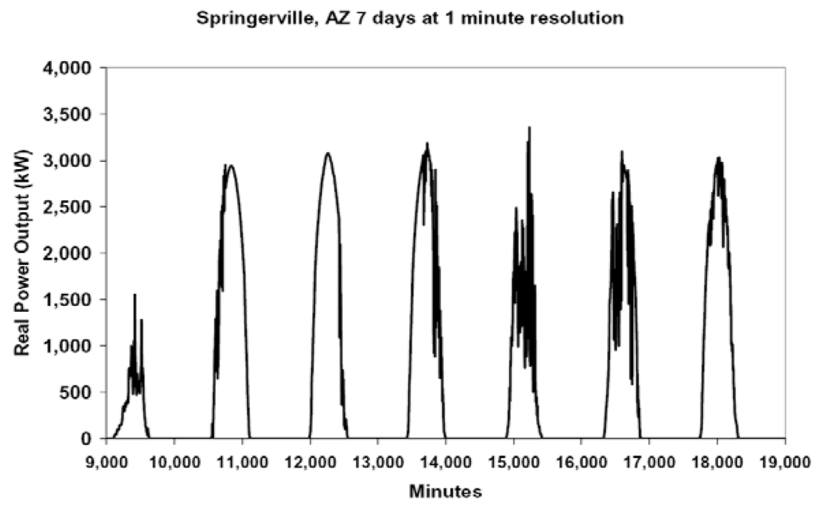
Power Tower and Dish Stirling Engine

Hybrid Gas-Solar Thermal Troughs

Short-term Support for Large-Scale Solar PV

- Solar photovoltaics exhibit short-term variable power output from cloud cover and other sources
  - Forms an integration issue for large-scale installations based on thin-film photovoltaic
- Short-duration storage (seconds to minutes) can help mitigate these fluctuations by reducing ramp rates
- Requires storage with high-cycle life and power density, without requiring large durations





Jay Apt and Aimee Curtright"The Spectrum of Power from Utility-Scale Wind Farms and Solar Photovoltaic Arrays", Carnegie Mellon Electricity Industry Center Working Paper, CEIC-08-04

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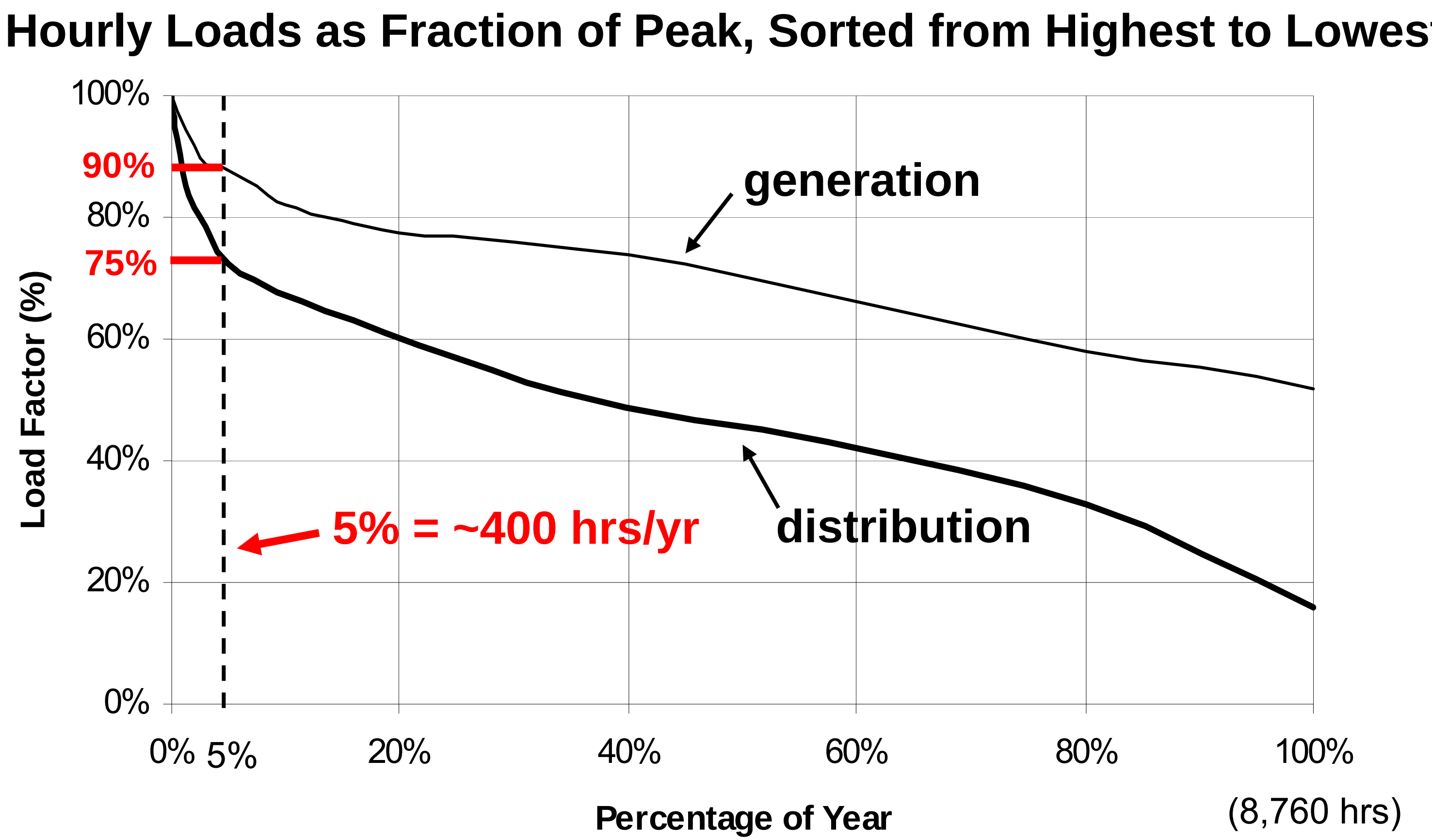
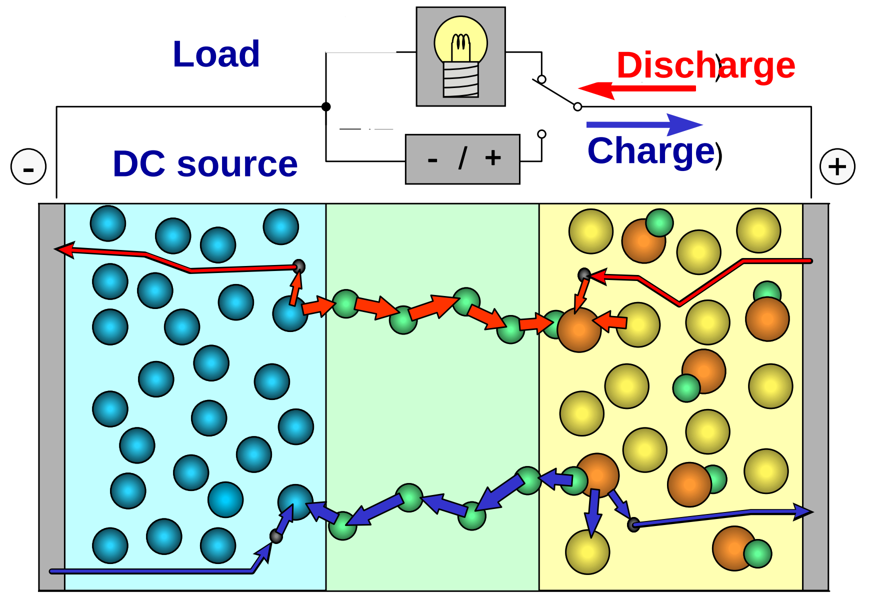
Reducing Peak Demand in Urban Load Centers

Optimal Utilization of Grid Assets



25% of distribution & 10% of generation assets (transmission is similar), worth of 100s of billions of dollars, are needed less than 400 hrs/year!

NaS Battery Technology Chemistry



Negative Electrode (Na)

Solid Electrolyte (β-Alumina)

Positive Electrode (S)

$$2Na + xS \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} Na_2S_x \quad (\text{EMF}: 2.08 \sim 1.78\text{V})$$

NA, elemental sodium

NA$^+$, sodium ion

S, elemental sulfur

Na_2S_x, sodium polysulfide

e$^-$, electron

Sodium Sulfur Batteries - NaS

Gaining Market Adoption for Grid Support Applications

1 MW /7.2 MWh   NYPA – End-User Peak Shaving

6MW / 48MWh at TEPCO's Ohito Substation

1 MW / 7.2 MWh NAS

AEP Substation

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Properties of NaS Battery Technology

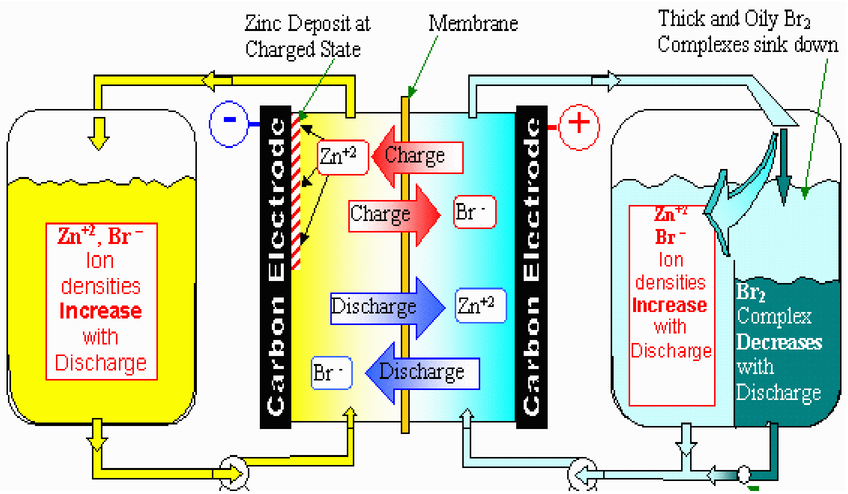
Energy Density (Volume)	170 kWh/m^3
Energy Density (Weight)	117 kWh/ton
Charge/Discharge Efficiency - Batteries (DC Base)	> 86%
Charge/Discharge Efficiency - System (AC Base)	≥ 74%
Maintenance	low
Cycle Life	2,500 cycles or more
Calendar Life	15 yr

Comparison of NAS Battery to Other Storage Technologies

- ADVANTAGES
  - High energy density (small substation footprint)
  - Relatively high cycle efficiency
  - Optimized for long discharges
  - Good “pulse power” capability
  - Fast response (battery < 2 msec)
  - No moving parts (e.g., pumps, valves)
  - Quick deployment and installation < 9 months
- DISADVANTAGES
  - Relatively expensive
  - Single supplier
  - Must be kept hot
  - Expensive to move to other sites

Zinc-Bromine Batteries

- Flow battery which stores energy in liquid electrolytes
  - Two different electrolytes flow past carbon-plastic composite electrodes in two compartments separated by ion permeable membrane
  - Energy stored in liquid electrolytes (bromine) on positive, and plated zinc layer on negative
  - Zinc layer dissolves as battery discharges, and is replated during charge



Zinc-Bromine Technology Characteristics

- Minimal maintenance requirements (few moving parts and low temperature operation)
- 30+ year life
- 100% depth of discharge over thousands of cycles
- ~70% round-trip efficiency
- Modular & scalable
- Environmentally benign: very low toxicity, 100% disposable or recyclable
- Can be placed indoors or outdoors – no need for separate environmentally controlled environment
- Fully integrated systems – including energy storage, power conversion, controls, thermal management, remote monitoring
- Easy to install or relocate

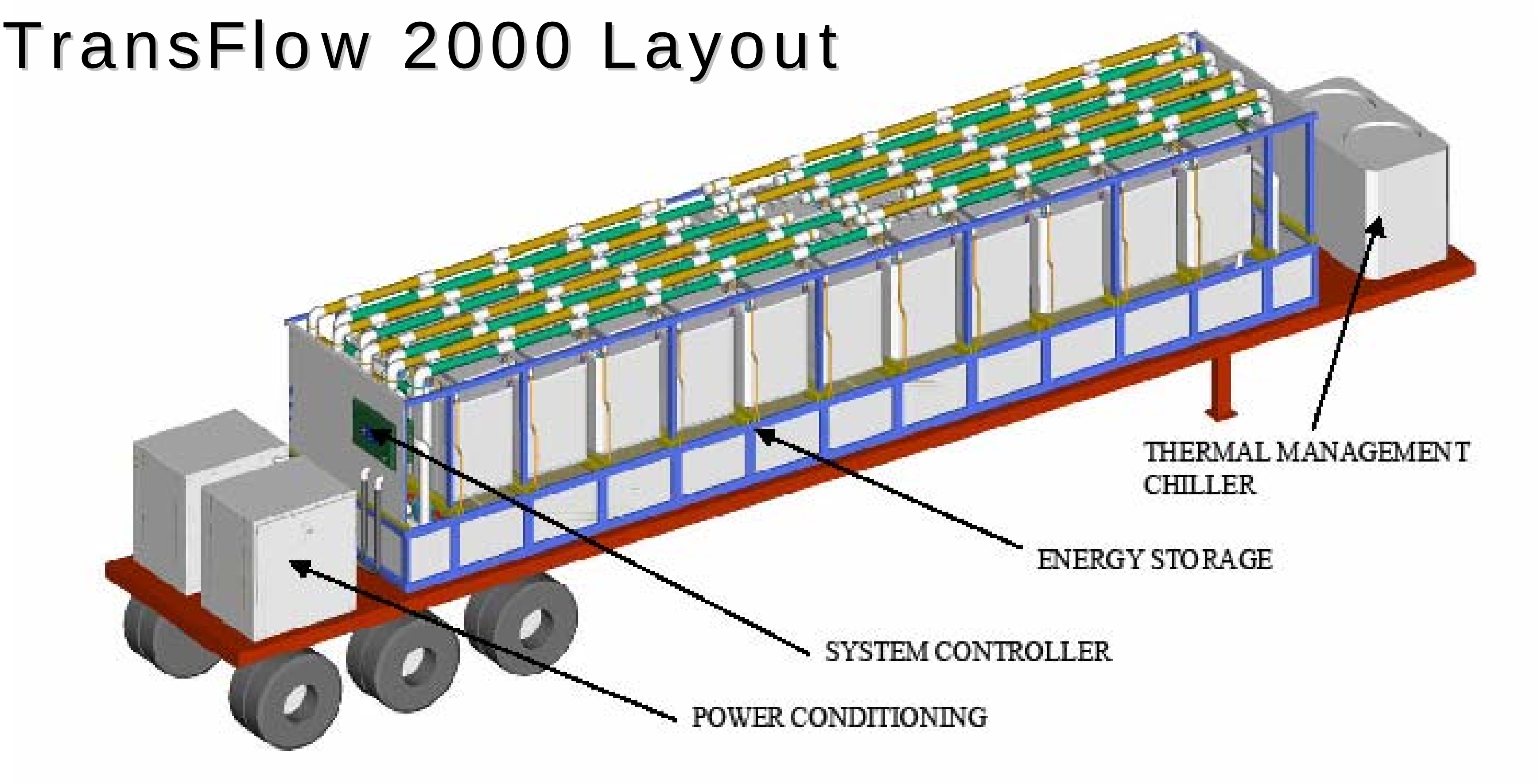
TransFlow 2000 Specifications

Premium Power ZnBr System

Performance:	
Energy Storage Capacity:	2.8 MWh
Voltage Input (3-Phase):	480VAC, 60Hz
Voltage Output (3-Phase):	480VAC, 60Hz
Maximum Continuous Power Delivery:	500kW
Power Factor (Input):	+/- 0.95
Voltage Harmonics:	<5% THD
Physical:	
Length:	53' (16.15m)
Width:	8.5' (2.59m)
Height (including trailer wheels):	13.5' (4.11m)
Weight:	96,000 lbs (43,545 kgs) (including electrolyte & trailer)
Safety:	
UL Listed	UL 1741
Federal Communications Commission	Part 15, Class A
National Fire Protection Agency	NFPA 1 & 70

Flow Batteries – Zn / Br

Gaining Market Adoption for Grid Support Applications



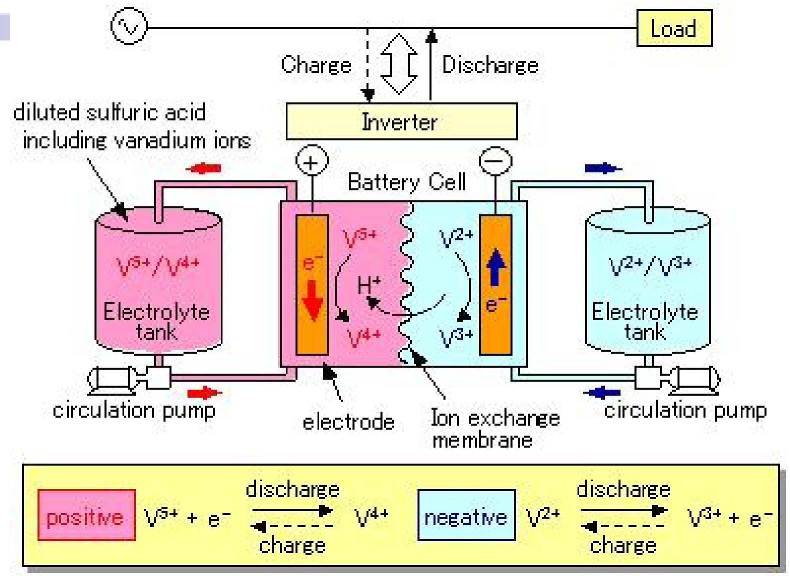
0.5 MW / 2 MWh

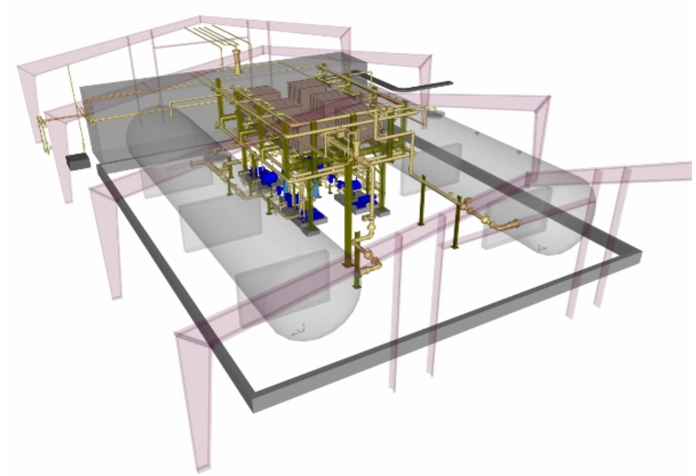
ZBB Energy Corporation

- Manufactures and sells grid-scalable flow battery systems (calls their product regenerative fuel cells)
- Based in US and Australia
- Two major products: 50 kWh and 500 kWh systems
- Customers include: Utilities, Energy Companies, and Telcos
- Products meet UL 1741, IEEE 519 standards, manufactured under ISO 9001 qualification

Vanadium Redox Flow Batteries

- Energy stored in liquid electrolytes
  - Charge storage in multiple valence states of vanadium ion in solution
  - Electrolytes charged and discharged while traveling through cell stack
- Independent energy and power sizing
  - Energy proportional to volume of electrolyte
  - Power proportional to size of cells





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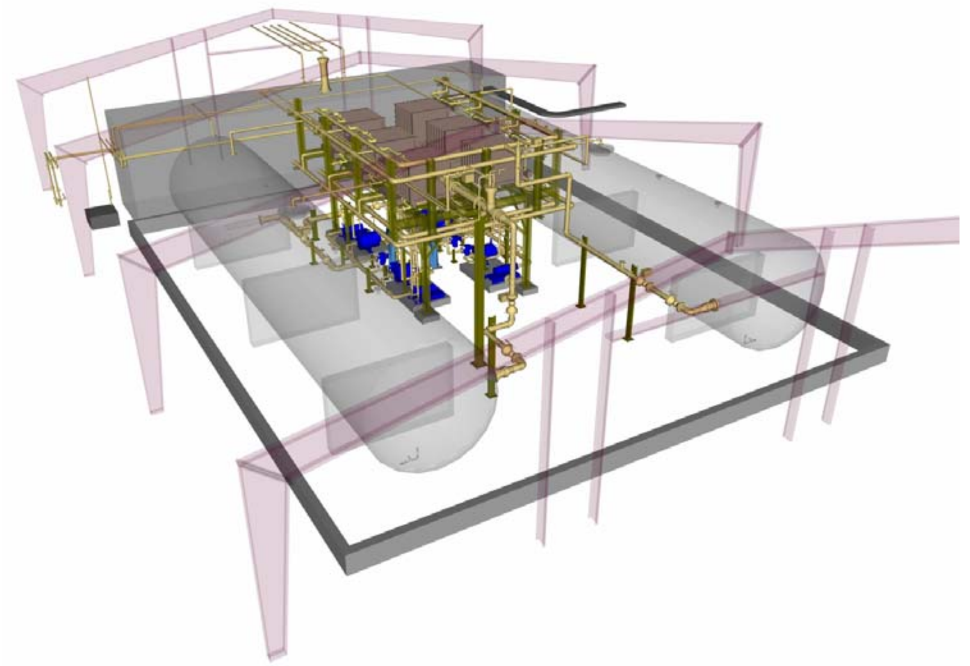
Major Vanadium Redox System Components

- Electrolyte Storage Tanks
- Regenerative Fuel Cell Stack
- Inverter/Rectifier



Other Flow Battery ReDox Couples

- Fe / Cr
- Zn / Cl
- Zn / Air
- H_2 / Br
- H_2 / Air

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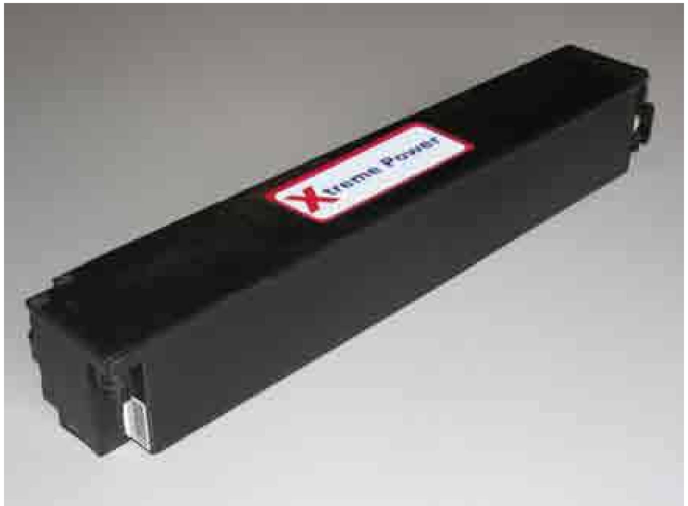
Advanced Lead Acid Batteries
Source: Xtreme Power

- 1 kWhr @ 3 Hour Rate
- 25 kW Instant. Power
- 5" x 5" x 30"
- 57 Lbs (25.9 kg)
- 12V Cell
- 2500 Amps for 30 Seconds – Pass/Fail Test

Gaining Market Applications in Wind (Hawaii); Peak Shaving; and Ancilliary Services

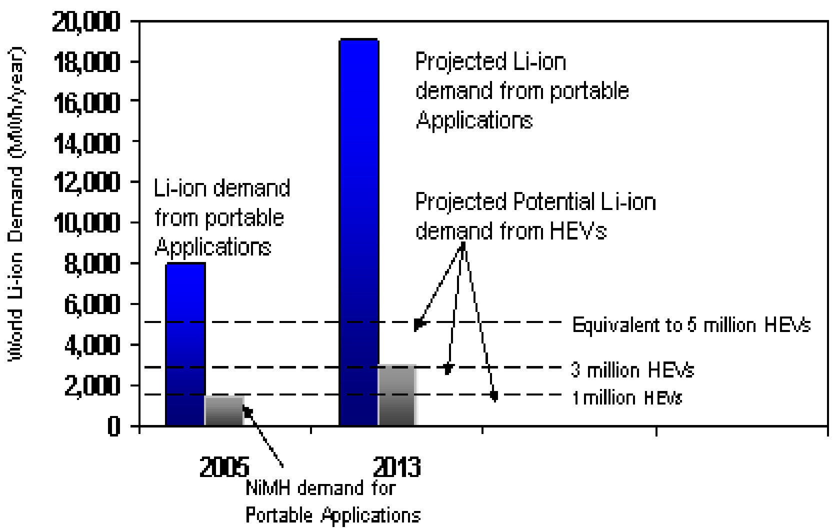


- Solid State "Dry Cell
- Improved Cycle life
- Improved efficiency

ZEBRA Battery

- Originally developed for vehicular applications – rapid charge/discharge capability
- Sodium Nickel Chloride (NaNiCl) electrochemistry
- Operates internally at 280°C
- Insensitive to ambient conditions
- High voltage (620Vdc)
- Long life – 5 to 10 years
- No internal corrosion mechanisms
- High energy and power density
- **100 KW system tested**

Emerging Li-ion Batteries
Significant Role in Distributed Energy Storage



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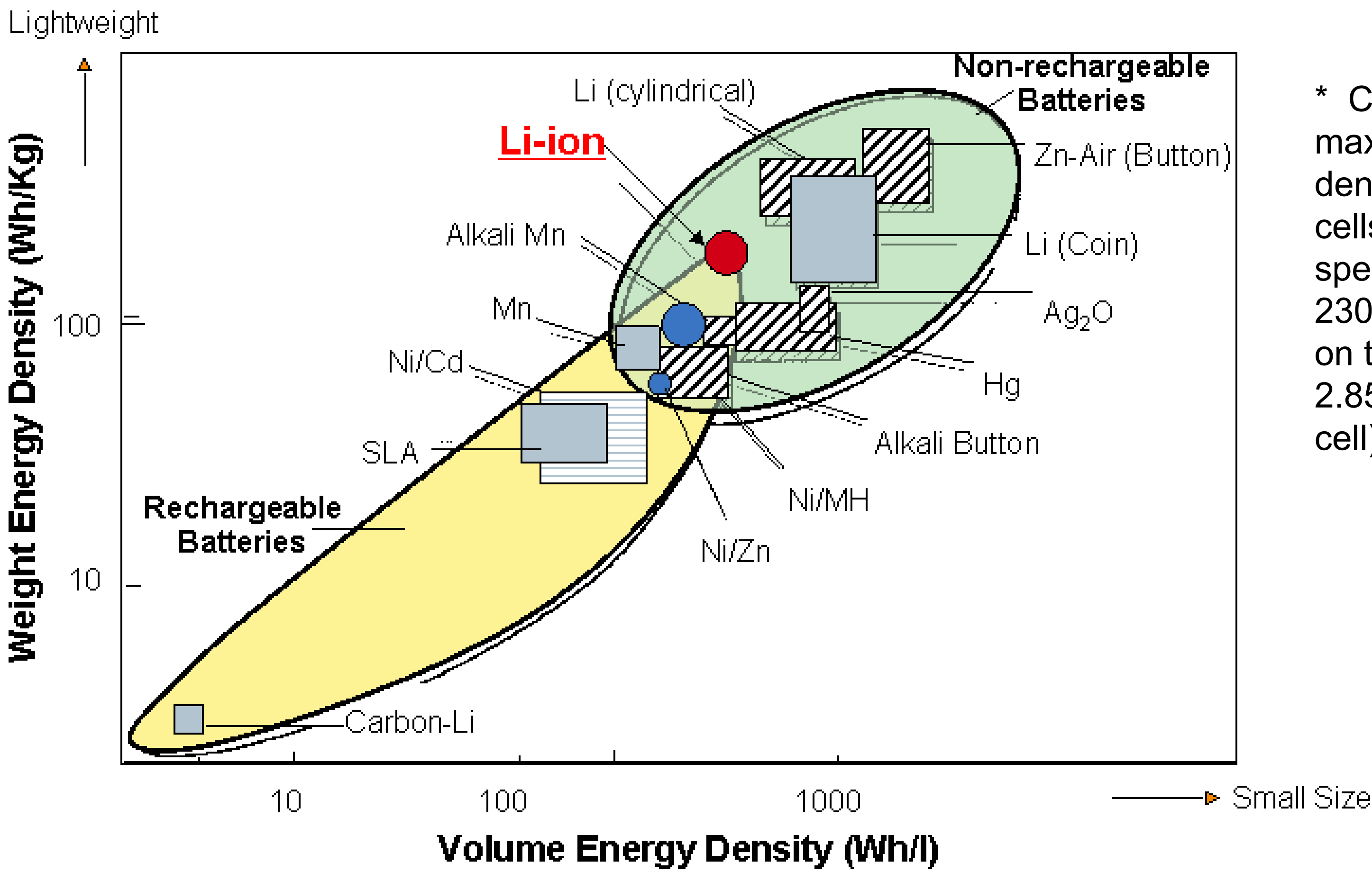
Lithium-ion batteries - Most Energy in the Smallest space.

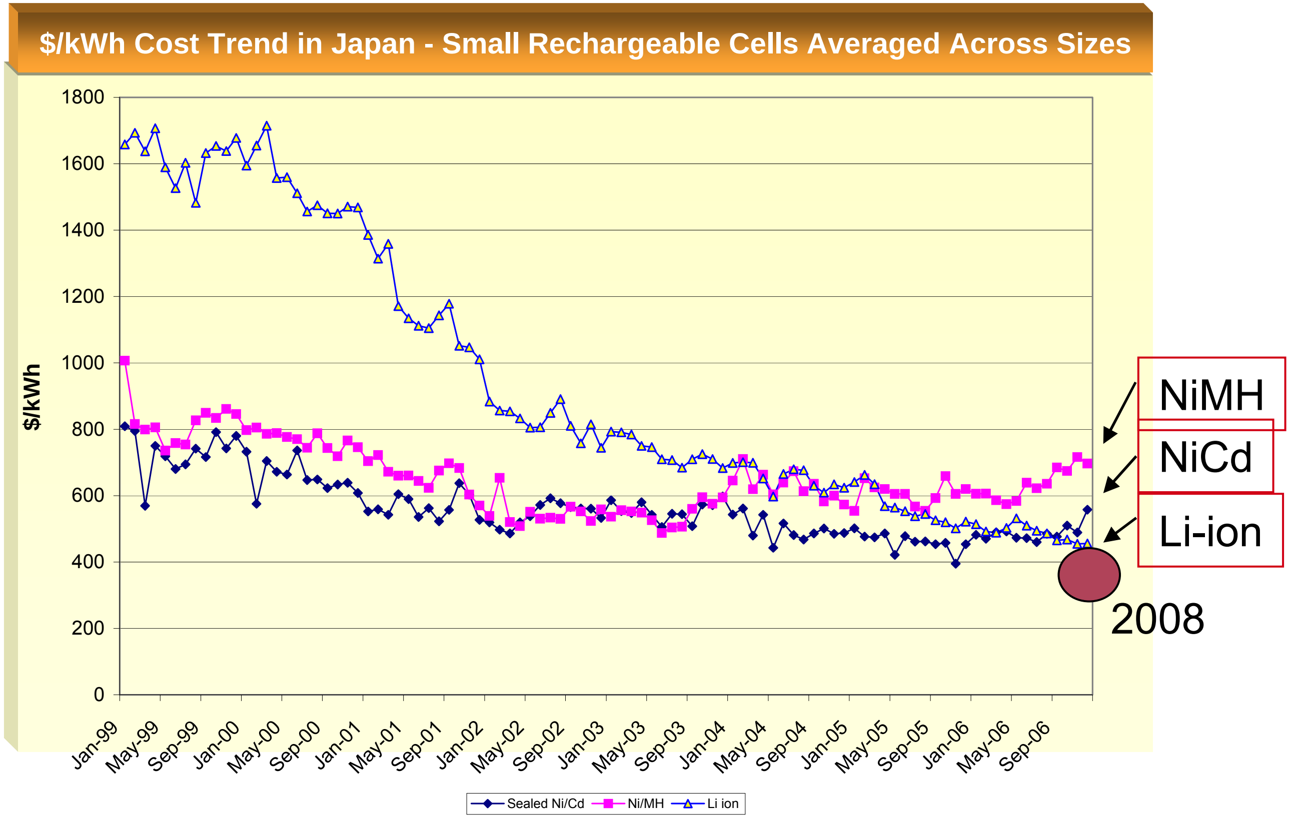


Created by TIAX based on Osaka, Y. Nishi, T. Kawase, *Key Technology Battery*, P21, Maruzen (1996)

* Currently, the maximum energy density for Li-ion cells 630 Wh/l and specific energy is 230 Wh/kg (based on the Panasonic 2.85 Ah 18650 cell).

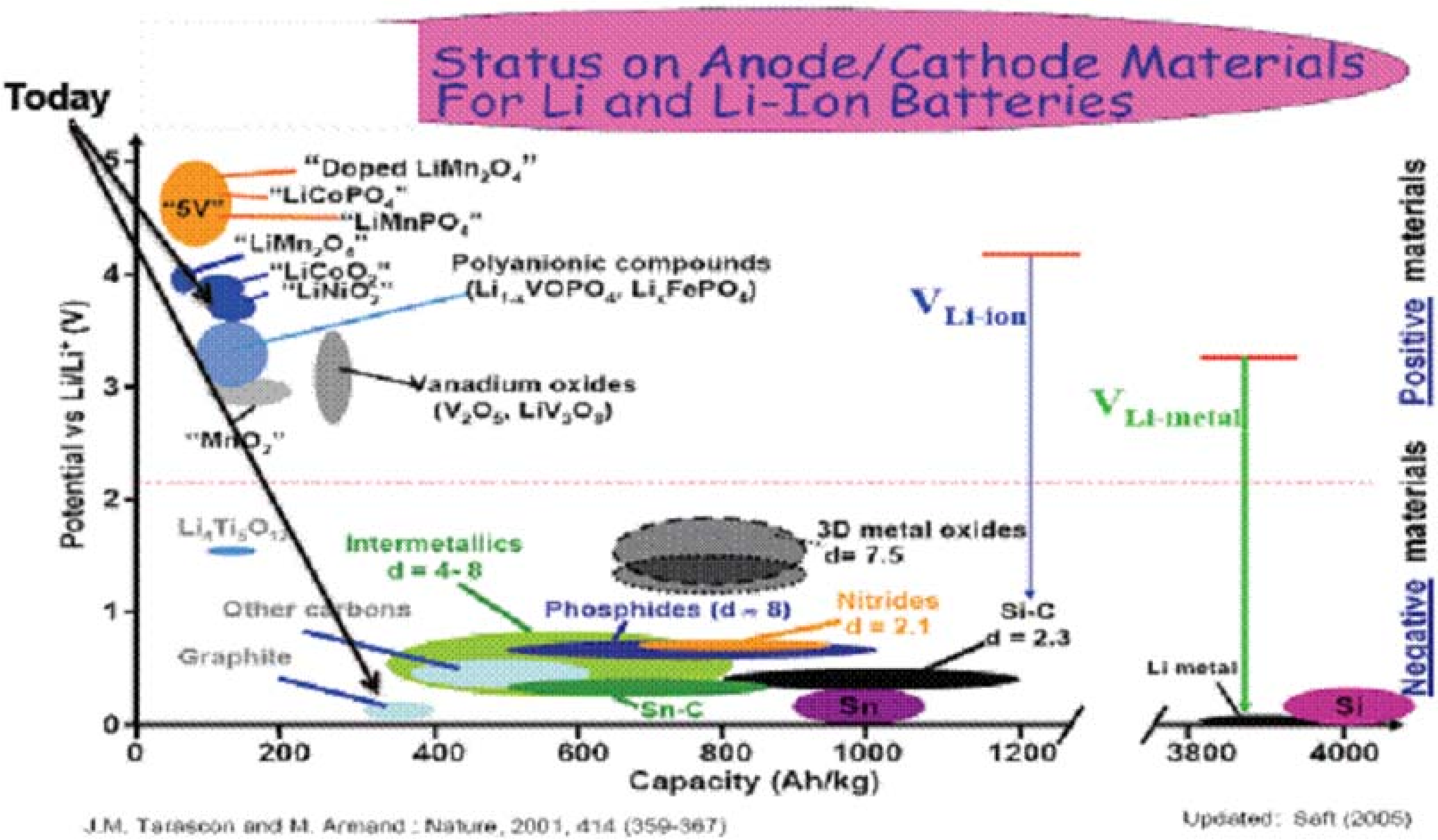
Li-ion OEM Cost Trends

Cost for producing Li-ion cells sized for portable electronics continues to decline – they are now lower than NiMH or NiCd.



Source: Created by TIAX based on METI data

Numerous Research Institutions are pursuing methods for increasing potential (v) and capacity (Ah/kg)



2 MW Lithium Ion System for Frequency Regulation at AES Power Plant

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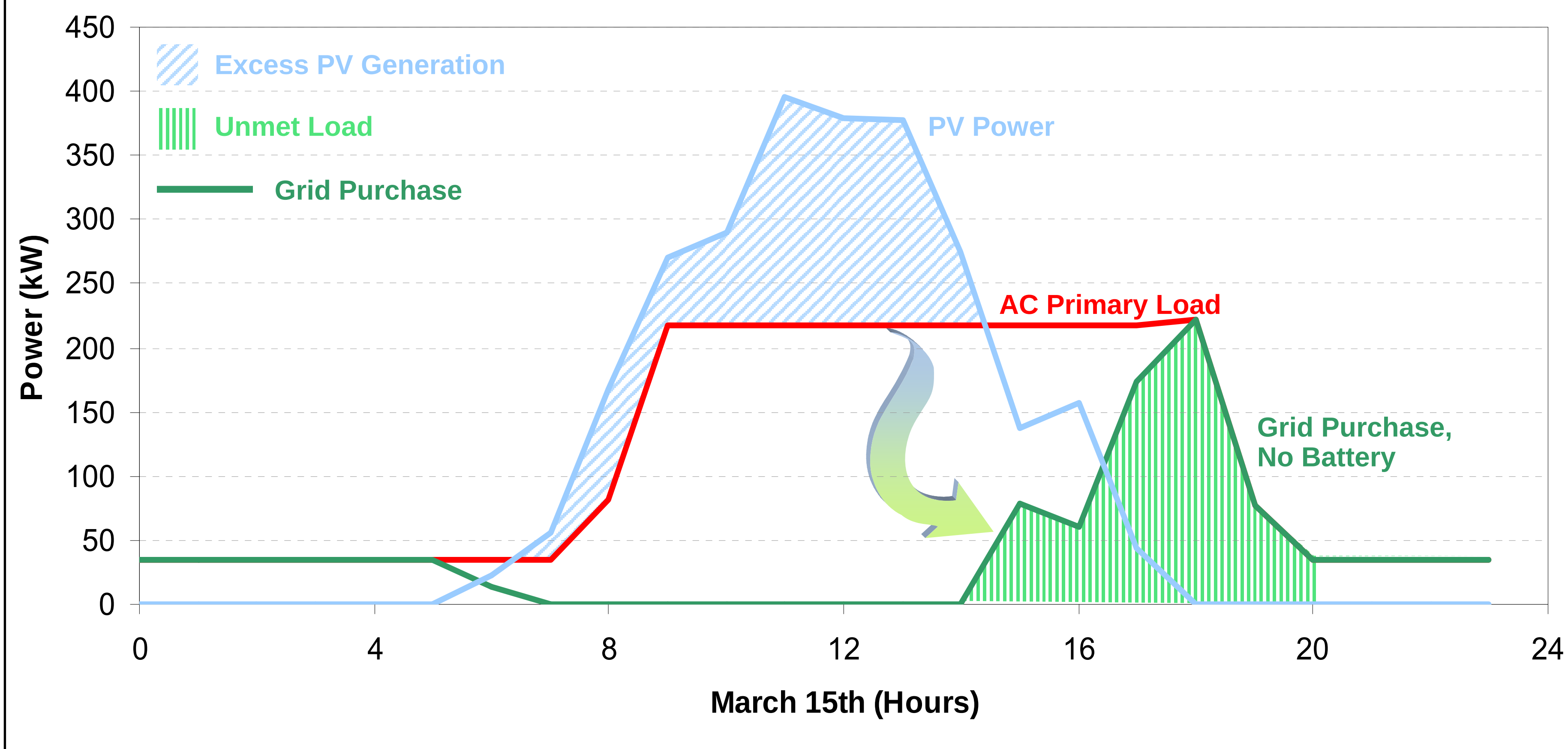
Emerging Li-ion Energy Storage Systems

- Fully Integrated Systems
- Numerous Applications:
  - Neighborhood Storage
  - Home / PV
  - Backup / UPS / Dispatachable
- EPRI planning to test several systems in 2009
- Future positioning for Smart Grid Demonstrations.

PV energy generation does not align fully with residential demand – leaving excess PV early in the day and unmet demand late in the day.

Use Storage to Capture Excess PV

(Sacramento, 100,000 sq ft office building, 400 kW PV, **600 kWh Battery**)



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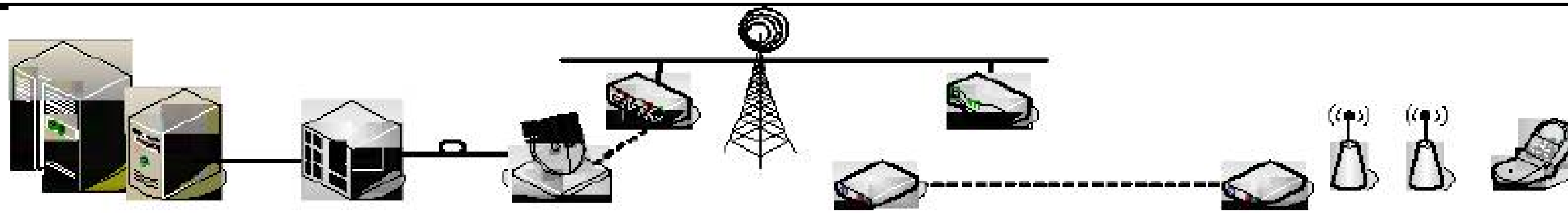
Smart Grid Demonstrations – Enabling Aggregation of Energy Efficiency and Dispersed Generation & Storage

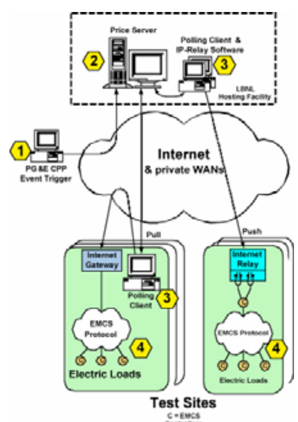


Communication Media: BPL, Wi-Max, Satellite, Fiber, DSL, Wi-Fi, RF Mesh, etc.

Smart Grid Infrastructure: Software/database, network communication and monitoring, and control architecture

Substation/Feeder DER Integration

C&I Customer Demand Response & DER Integration



Residential Customer Demand Response & DER Integration

Reduce Peak Demand, Enable Energy Efficiency, and Reduce CO_2 Footprint Through Dynamic Pricing & DER Integration

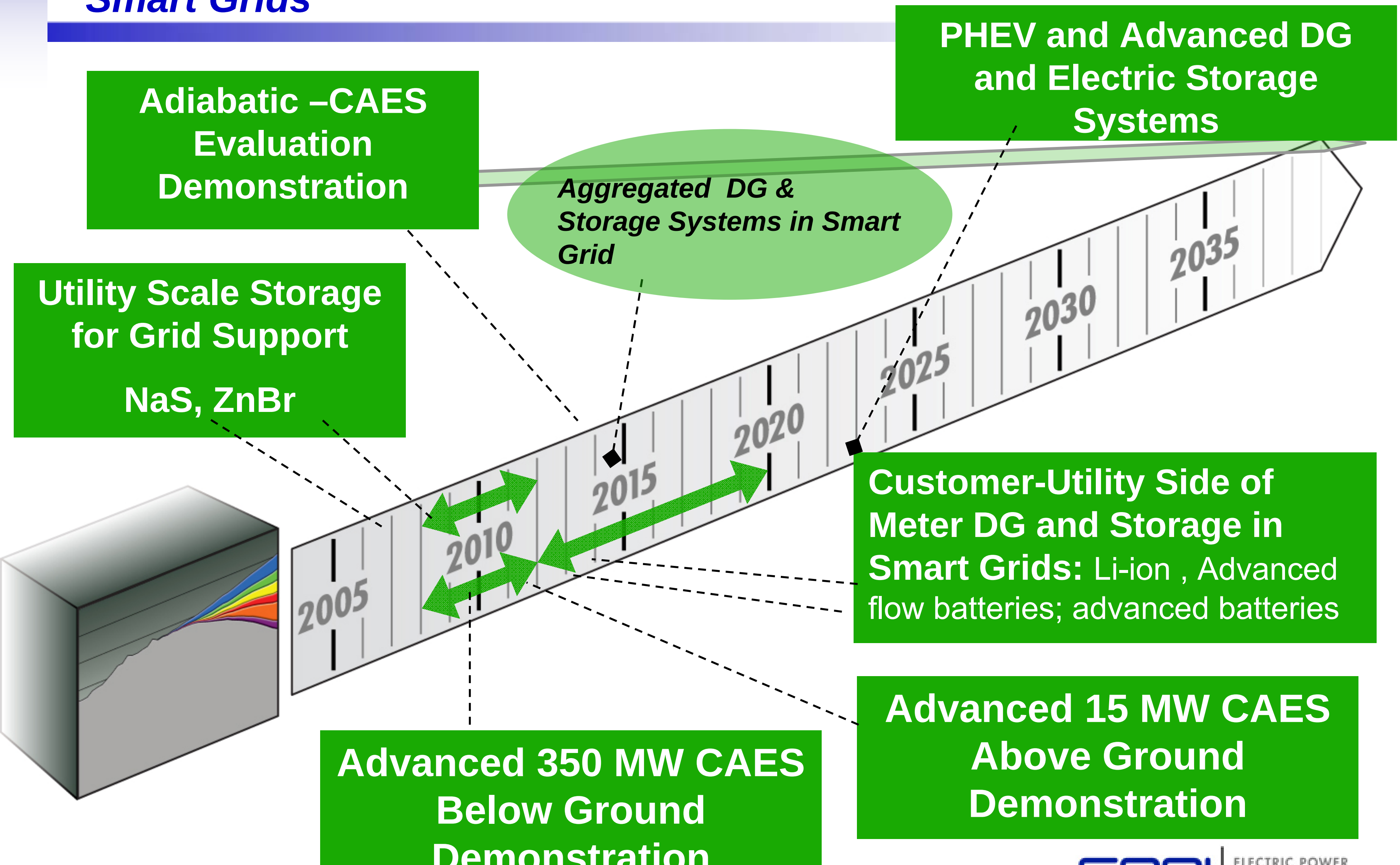
More Demonstration Needed!

- To meet continuous energy demands, load leveling, and grid ancillary services (to decouple demand from supply)
- Micro-Grid and Net-Zero-Energy Appliations
- Smart-Grid Deployments
- Increase Value and Use of Renewables

Collaboration Opportunities with Electric Utilities and EPRI to advance Electric and Thermal Storage Solutions

Energy Storage Road Map

Enabling Mgt of Peak-loads and Intermittent Renewables via Smart Grids



Summary

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- The Electric Sector Emits over 30% of the US GHG Emissions; A Full Portfolio of Supply and Demand Energy Solutions will be needed;
- The Future Generation Mix will include a portfolio Variable Renewable Generation Sources;
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- Energy Efficiency and advanced load management and control will be an essential part of the solution – enabled by a 'Smart Grid'
- Numerous electric energy storage systems are available **today** for application in Zero-Net-Energy Applications
- More Energy Storage Demonstrations are needed!

Electric Energy Storage is an Essential Asset in the Smart Grid

Thanks for your Attention!

Together…Shaping the Future of Electricity

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